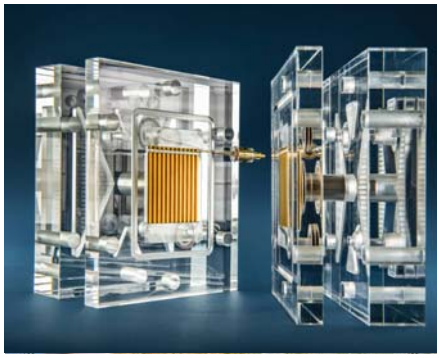
Towards Low-cost and Efficient Hydrogen Production by PEM Water Electrolysis – Design and Performance Optimization for a High-pressure Stack

Results of the European Project "NOVEL"



Tom Smolinka, Thomas Lickert, Patricia Gese and Andreas Georg

Fraunhofer Institute for Solar Energy Systems ISE

21st WHEC , Parallel Session 2

Zaragoza, June 13th, 2016

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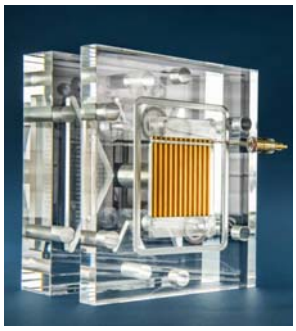
Outline

- Fraunhofer ISE and the European NOVEL project
- Cost Break Down for PEM electrolysis stacks
  - Main set-up and results
  - Cost reduction strategies
- Stack components
  - Membrane electrode assembly
  - Porous transport layers
- Stack optimization
  - Sealing and contact pressure
  - Passivation of BPP and ICR



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Fraunhofer Institute for Solar Energy Systems ISE
Research for the Energy Transformation

- Largest research institute for solar energy in Europe
  - Established: 1981
  - Staff: 1,100 (with students)
  - Budget 2015: € 83.7 million
- Over 1,000 ongoing R&D projects in the fields of
  - Photovoltaics
  - Solar Thermal Technology
  - Building Energy Technology
  - Hydrogen Technology
  - Energy System Technology

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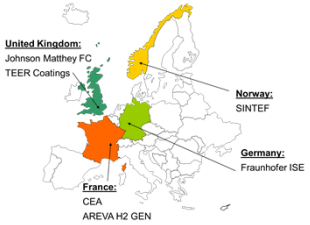
The NOVEL Project
Novel Materials and System Designs for Low Cost, Efficient and Durable PEM Electrolysers

PSI · SINTEF · cea · Fraunhofer ISE

New Materials Development (Electrocatalysts & Membranes) → Component development and testing → Increased understanding of lifetime and degradation → Stack and system design

Innovation in Motion Miba · Johnson Matthey Fuel Cells · AREVA H_2Gen

- Run time: 09/2012 – 11/2016
- Funding / total budget: €2.67m / €5.74m
- Main objectives:
  - Materials for > 75% efficiency (LHV)
  - EL stack cost < €2,500 / $Nm^3\ h^{-1}$
  - Target lifetime of 40,000 h (< 15 µV h^{-1})



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* Don't miss the talk of M. Thomassen: Session 4 , Room 7, Tuesday 14th, 16:10

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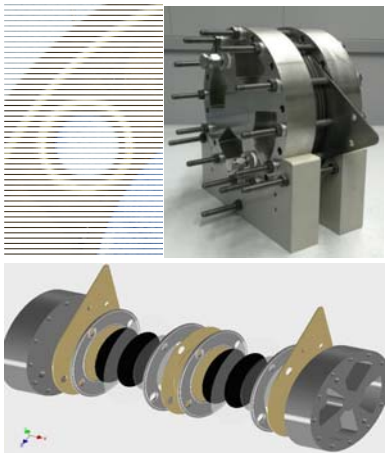
The NOVEL Project
General features of the PEM stack platform

- Short stack with 150 cm² previously developed in the NEXPEL project
- Circular design for pressures up to 50 bar (operation at 30 bar)
- Pressure balanced cells with water supply on anode side
- Ti sheets as BPPs w/o machined flow field structures
- Multilayer porous transport layers
  - porous Ti mesh/felt (anode)
  - porous C paper (cathode)
- Plastic frames with dispensed sealings



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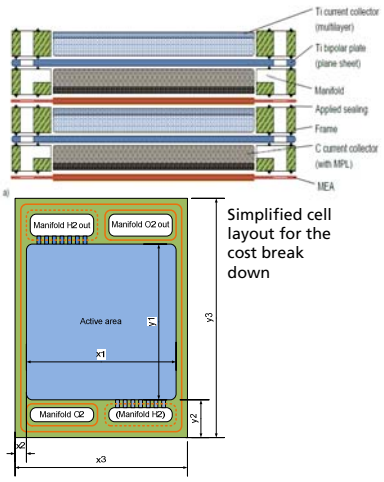
Cost Break Down
What is considered?

- Cost break down for three different stack sizes
- "State-of-the-Art" materials
  - Nafion 117 based CCM with PGM electrodes
  - Ti BPP with "standard" coating
- Cost calculated according to quotations

Size (cell area)	[cm²]	300 / 600 / 1200
Nominal cell voltage	[V]	1.80
Current density	[A/cm²]	2.00
Voltage efficiency	[-]	82%
Operating pressure	[MPa]	3.0
Op. temperature	[K]	353
Cells / stack	[-]	100
Stack power	[kVA]	108 / 216 / 432
H2 production rate	[Nm³/h]	24.4 / 48.8 / 97.6



Simplified cell layout for the cost break down

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BPP: Bipolar plate
CCM: Catalyst coated menbrane
PGM: Platinum-group metals

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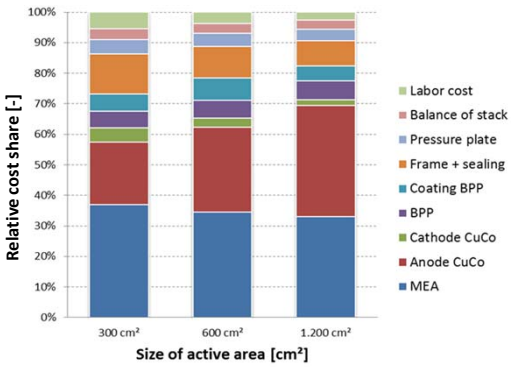
Cost Break Down
Relative cost share for three different stack sizes



Cost share for 100 stacks produced:

- Relative cost of the MEA depends only slightly on the cell size
- Anode PTL becomes dominantly as required thickness increases (proper flow regime)
- Ti sheets as BPPs have only a small cost share (initial idea of this stack design)
- KPI of MAWP can be reached!

352	309	281	[€/kW]
1,558	1,366	1,242	[€/Nm³ H_2]
1.27	1.11	1.01	[€/cm²]

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KPI: Key performance indicator
MEA: Membrane electrode assembly
MAWP: Multi-annual work proramme

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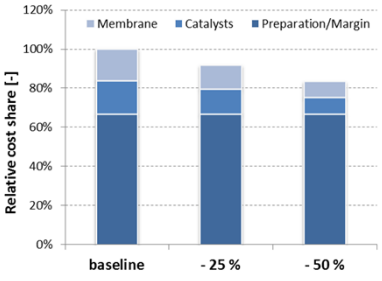
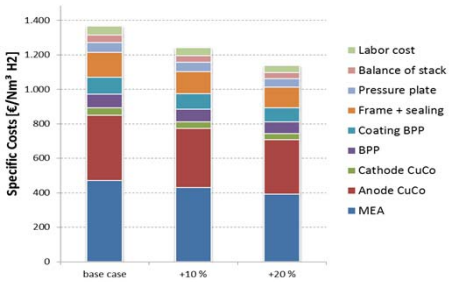
Cost Break Down
Cost reduction strategies





- Reducing PGM loading and membrane cost has only small impact on cost share
- With increased CCM volume production costs come down significantly
- Shifting operating point towards higher current densities
- Benefit from low internal ASR
  - Increase membrane conductivity
  - Increase catalytical activity

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ASR: Area specific (cell) resistance
CCM: Catalyst coated menbrane
PGM: Platinum-group metals

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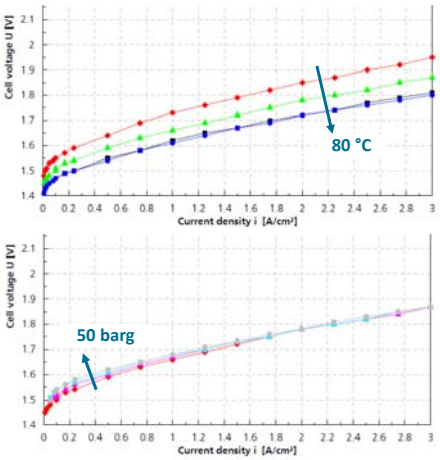
Stack Components: Membrane Electrode Assembly
Towards high current densities – NOVEL MEA from JM

- Developed at Johnson Matthey
  - Adapted automotive membrane
  - Thickness: ~60 µm
  - Reinforced structure
  - Containing PGM-type H_2 / O_2 recombination catalyst
- Screening in 25 cm² single cells
- Standard test protocoll for MEAs
  - 12 h conditioning @ 80 °C
  - Temperature: 80 - 40 - 60 - 80 °C
  - Pressure: 1 - 10 - 30 - 50 barg

➔ High voltage efficiency

➔ Operation at high current densities



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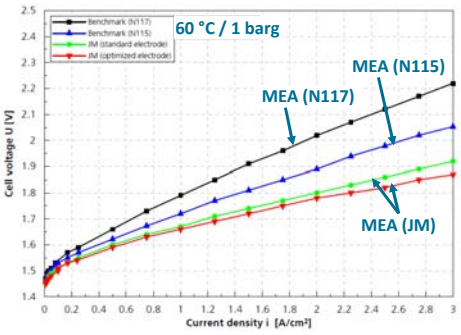
Stack Components: Membrane Electrode Assembly
Comparison with benchmark MEAs

- Comparison at 60 °C and 1 barg
- Commercial MEAs with thicker membrane N115 and N117
- Different electrodes investigated (PGM loading, ionomer content)
  - Excellent short-term performance
  - Long-term stability needs to be proved




Test cell as used for MEA characterisation

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* Don't miss the talk of F. Fouda-Onana:
Session 3 , Room 1, Tuesday 14th, 10:30

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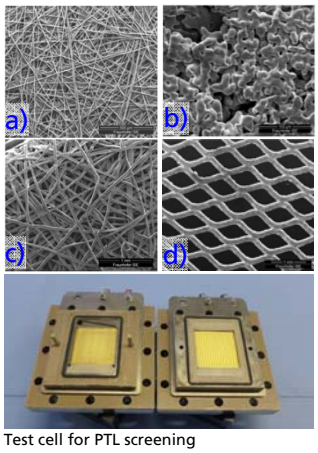
Stack Components: Porous Transport Layer
Single cell screening for pre-assessment

- Different materials available
  - Carbon paper (a) with/without MPL
  - Sintered Ti particles/felt/mesh (b/c/d)
  - Sintered Ti hybrid PTL
- Porous Ti highly sensitive to stack cost
- Screening in 25 cm² single cells
  - Polarisation curves up to 5 A/cm²
  - Variation of
    - Temperature
    - Pressure
    - Flow rate



Test cell for PTL screening

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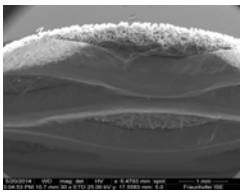
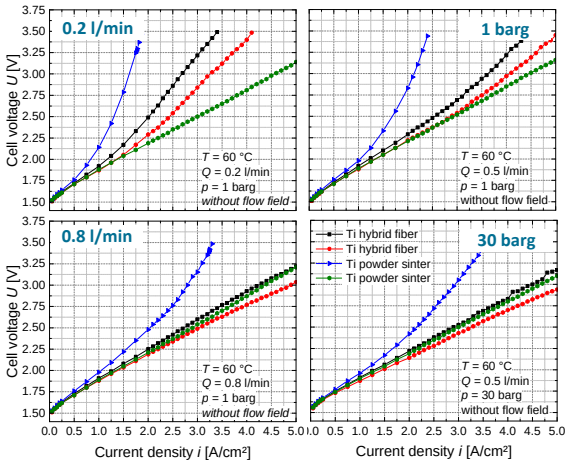
Stack Components: Porous Transport Layer
Single cell screening for pre-assessment

- Selection of porous transport layer has to be done in accordance with stack design and operating window
- Good trade-off: Ti based hybrid PTL (mesh and felt)





Federal Ministry of Transport and Digital Infrastructure
nip
PTL: Porous transport layer
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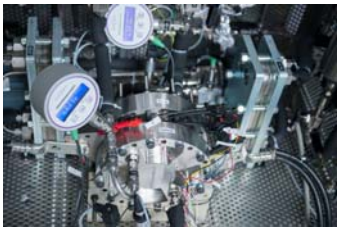
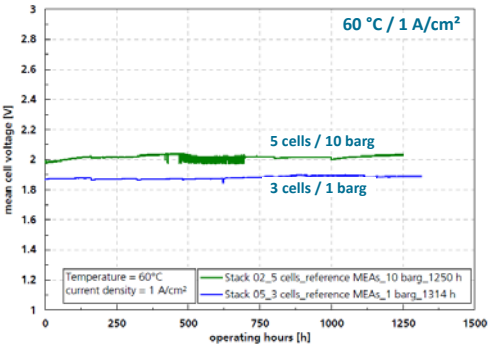
Stack Optimization
Adjustment of sealing and PTL compression

- Preliminary results on short stacks with commercial MEAs
- Adjustment of
  - PTL type and thickness
  - Compression rate (cathode)
  - Sealing elevation





Test-up for short stack measurements

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PTL: Porous transport layer

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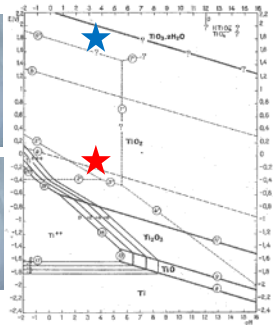
Stack Optimization
Oxide formation on Ti BBP and PTL

- Passivation of uncoated titanium on both sides by TiO_2
- Thickness determination via optical reflectance measurements
  - Anode: 10 - 20 nm of TiO_2 on Ti (high potential → dense layer)
  - Cathode: 10 - 50 nm of TiO_2 on Ti (low potential → porous layer)
- Very fast formation of oxide layer on both sides



Harsh conditions (cathode)

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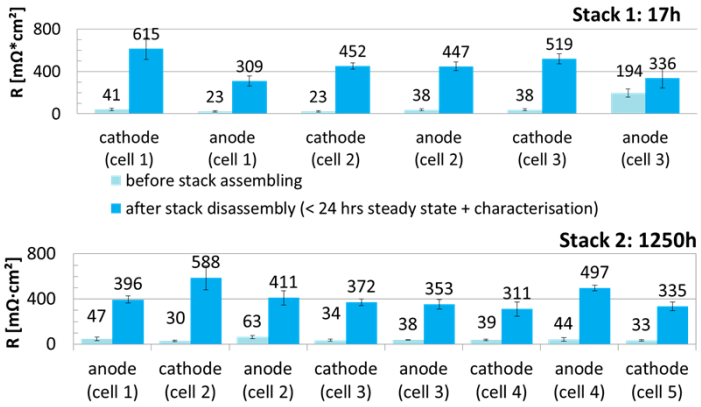
Stack Optimization
Interfacial contact resistance (ICR)

- ICR measurements of BPP before and after stack operation (against carbon GDL)



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GDL: Gas diffusion layer
ICR: Interfacial contact resistance
BPP: Bipolar plate

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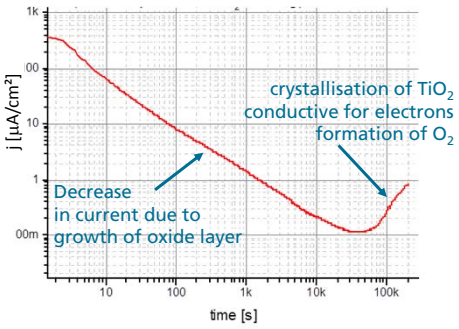
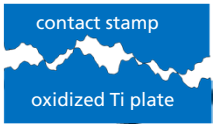
Stack Optimization
Interfacial contact resistance (ICR)

- Ex situ characterisation by LSV, CA, ICR
  - Chronoamperometry on uncoated Ti (2V vs. SHE, RT, no O2 bubbling)
  - CA → MΩ cm²
- Ex situ characterisation does not confirm in situ HFR measurements
- "Scratching" effect in ICR set up:
  - TiO_2 vs. C paper GDL: 810 mΩ cm²
  - TiO_2 vs. Ti sinter PTL: 7.7 mΩ cm²
- "Scratching" as well in EL cell!
  - Cathode side: BPP // PTL
  - Anode side: PTL // electrode





Interfacial „micro-contact points" of two rough surfaces

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CA: Chronoamperometry
ICR: Interfacial contact resistance
LSV: Linear Sweep Voltammetry

BPP: Bipolar plate
GDL: Gas diffusion layer
PTL: Porous transport layer

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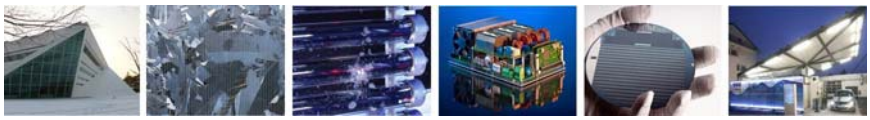
  - www.windgas-hamburg.com

Thank you for your attention!



Fraunhofer Institute for Solar Energy Systems ISE

Dr. Tom Smolinka

www.ise.fraunhofer.de

tom.smolinka@ise.fraunhofer.de